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Evaluating the quality of riparian forest vegetation: the Riparian Forest Evaluation (RFV) index

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Abstract

Aim of study: This paper presents a novel index, the Riparian Forest Evaluation (RFV) index, for assessing the ecological condition of riparian forests. The status of riparian ecosystems has global importance due to the ecological and social benefits and services they provide. The initiation of the European Water Framework Directive (2000/60/CE) requires the assessment of the hydromorphological quality of natural channels. The Directive describes riparian forests as one of the fundamental components that determine the structure of riverine areas. The RFV index was developed to meet the aim of the Directive and to complement the existing methodologies for the evaluation of riparian forests.

Area of study: The RFV index was applied to a wide range of streams and rivers (170 water bodies) in Spain.

Material and methods: The calculation of the RFV index is based on the assessment of both the spatial continuity of the forest (in its three core dimensions: longitudinal, transversal and vertical) and the regeneration capacity of the forest, in a sampling area related to the river hydromorphological pattern. This index enables an evaluation of the quality and degree of alteration of riparian forests. In addition, it helps to determine the scenarios that are necessary to improve the status of riparian forests and to develop processes for restoring their structure and composition.

Main results: The results were compared with some previous tools for the assessment of riparian vegetation. The RFV index got the highest average scores in the basins of northern Spain, which suffer lower human influence. The forests in central and southern rivers got worse scores. The bigger differences with other tools were found in complex and partially altered streams and rivers.

Research highlights: The study showed the index's applicability under diverse hydromorphological and ecological conditions and the main advantages of its application. The utilization of the index allows a better understanding of the status of riparian forests, and enhances improvements in the conservation and management of riparian areas.

Key words: riparian quality; Water Framework Directive; connectivity; indicator; hydromorphology.

Introduction

Riparian forests are one of the most valuable ecological elements of river systems. They maintain high levels of biological diversity and productivity and provide dynamic habitats for many different species (Bennett and Simon, 2004). They also provide many other ecological and social benefits and ecosystem services, performing critical functions in both hydrological and biogeochemical cycles, protecting water quality, and providing important habitats for a rich diversity of flora and fauna (Naiman and Décamps, 1997; Lohman, 2004). These attributes are closely related to a range of hydric conditions that determine the quality of riparian forests as refuges for a large number of species that inhabit riverine environments. However, riparian forests have been subjected to progressive alteration in the last centuries, mainly due to human pressures (particularly river regulation and agricultural development, but also forestry, gravel mining or urban occupation) that have greatly degraded their ecological structure and function (Hughes, 2003).

The reduction and alteration of riparian forests have resulted in an increase in scientific and technical work related to understanding these ecosystems and their protection and recovery (Naiman *et al.*, 1993; Hughes, 2003). The Water Framework Directive (WFD) (2000/60/EC) and other directives have recognised the structure of riparian areas as one of the core features for use in the hydromorphological assessment of freshwater bodies. Some authors (Gurnell and Gregory, 1995; Bendix and Hupp, 2000; Richter and Richter, 2000) have analysed the interactions between hydrological and biomorphological processes, highlighting the importance of riparian stands in the

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overall status of fluvial ecosystems. Thus, monitoring has become fundamental to assess the impacts of human activities on ecological functioning and the effectiveness of changes in management (NRC, 2002).

However, in most cases, the status of riparian forests worldwide has not been well analysed, and they are most likely one of the least-understood ecological features of rivers. There are few comprehensive procedures capable of assessing the status of the core elements of riparian stands. In most cases, these procedures are not at all associated with the hydromorphological functioning of the river, complicating further discussions about the causes of the alteration and the available measures for restoration (Hughes, 2003).

In Spain, a diverse array of water and biodiversity decrees and laws require that water and natural resource managers assure the protection of riparian vegetation. A wide range of measures is to be adopted to preserve the quality of riparian forests. For instance, environmental flow requirements are also to be calculated based on their needs (*e.g.* Spanish Law 11/2005, and Decree 907/2007).

Different indexes have been proposed for the assessment of riparian stands (Table 1). However, most of those indexes have shown different problems in their application or results (*e.g.* the delineation of study reach not representative of the overall area, strictly based on woody vegetation, not linked to the river structure, too resource intensive, results difficult to interpret, etc.) (Kleynhans *et al.*, 2007; Magdaleno *et al.*, 2010). In fact, few of these protocols have been found to integrate the diverse dimensions of the functioning of riparian forests on the basis of the dominant hydromorphological processes typical in river systems. Furthermore, they are not related to the specific dimensions of fluvial ecosystems. The range of riparian widths oscillates across meters and hundreds of meters, and the complexity of the forest structure and composition is also largely variable. Thus, surveys should preferably be adapted to the river pattern and supply a real image of the overall quality of the riparian stands.

The main goals of this paper are as follows: (i) to develop an easy-to-apply fieldwork methodology for the assessment of riparian stands; (ii) to develop an improved tool to evaluate and interpret changes in riparian areas; (iii) to provide technicians and managers with a river-based procedure for the assessment of the quality of riparian vegetation, and the selection of the most necessary actions for its improvement or restoration.

Material and methods

A description of the RFV index

The parameters that constitute the RFV (Riparian Forest eValuation) index are based on the ecological connectivity of riparian vegetation. Although forest connectivity has normally been considered in spatial terms, temporal changes are of equal importance (Amoros and Bornette, 2002). These temporal-spatial relationships between connectivity and ecosystem dynamics have been analysed with respect to fluvial geomorphology (*e.g.* Poole, 2002), landscape ecology (Kondolf *et al.*, 2006), biodiversity maintenance (*e.g.* Liebold and Norberg, 2004), nutrient cycling (Stanley *et al.*, 1997) and food web structure (Woodward and Hildrew, 2002).

The RFV index has been designed to assess the spatial connectivity of riparian vegetation (in its three dimensions: longitudinal, transversal and vertical). But also the regeneration capacity of this vegetation, which guarantees its continuity in the future (Magdaleno *et al.*, 2010) The forest features selected were those connected to the essential hydromorphological and biological processes occurring in the riparian areas (Fig. 1).

Considering the vast hydromorphological variability among Spanish basins, the index was designed to include an assessment procedure that incorporates the structure and function of different river systems. These elements (structure and function) are influenced by diverse variables (*e.g.* the type and gradient of the valley, soil controls, riparian vegetation and land uses), but the flow regime is most likely the most influential variable in the development of the geomorphic attributes of river systems (Bendix and Hupp, 2000; Bunn and Arthington, 2002; Sidle and Onda, 2004; Hupp and Rinaldi, 2007). The dominant (channel-forming) discharge of a river is closely related to these attributes. The most relevant attribute is the relationship between the dominant flow and the bankfull width (Simonson *et al.*, 1994; Peck *et al.*, 2003; Schmidt and Potyondy, 2004).

Thus, the connectivity thresholds used in the RFV index are determined both according to and proportionally to the bankfull width of the river channel, which is not dependent on the time of the year when the analysis is performed. This approach links the assessment area to the channel dimensions, avoiding over-evaluation in small systems or under-evaluation

Table 1. Previous indexes proposed for the assessment of riparian stands, with indication of name, original author(s), procedure or scope, and places of application

Index	Authors	Procedure or scope	Places of application
QBR (Qualitat del Bosc de Ribera)	Munné *et al.* (1998, 2003)	Summation index of four components: — Total riparian vegetation cover (% of cover of any kind of plants except annual species — Cover structure (% of cover due to trees, shrubs and other low lying vegetation) — Cover quality (number of species of native riparian trees and condition of forest structure — Channel alterations (morphological man-made changes and artificial structures) Each component is calculated independently. The individual score of each part can not be either negative or higher than 25.	— Different national and regional Spanish basins (Suárez and Vidal-Abarca, 2000) — Queensland, Australia (Pettit, 2002) — Ohio, USA (Colwell and Hix, 2008) — Chile (Fernández *et al.,* 2009) — Argentina (Kutschker *et al.,* 2009)
IVF (Fluvial Vegetation Index)	Gutiérrez *et al.* (2001)	Weighted aggregation of the plant cover of species. Assignment of value to species based on its autochthonous or allochthonous characteristics.	— Catalonia (Spain)
RVI (Riparian Vegetation Index) and VEGRAI (Riparian Vegetation Response Assessment Index)	Kemper (2001), Kleynhans *et al.* (2007)	Assessment of a wide array of metrics (cover, abundance, structure, composition and recruitment) and applied according to the hydromorphological zonation (marginal, lower and upper strips) in a representative sub-reach of the river	— South Africa
RVI (Riparian Vegetation Index)	Aguiar *et al.* (2009)	Multimetric index of biotic integrity Categorical components: composition (*e.g.* cover and number of alien and endemic species) and functional metrics associated with life cycle and reproduction (*e.g.* numbers of perennial species) or trophic status (*e.g.* proportion of nitrophyllous species)	— Portugal
VIBI (Vegetation Index of Biotic Integrity)	Mack (2001), López and Fennessy (2002), Miller *et al.* (2006), Coles-Ritchie *et al.* (2007)	Ecological quality of vegetation in wetlands	— Colorado (USA)
Other: indexes used for assessing riparian habitat quality	Raven *et al.* (1998), Bunn *et al.* (1999), Salinas *et al.* (2000), Winward (2000), Ferreira *et al.* (2005), Johansen *et al.* (2008)	Indexes not specifically designed to describe the status of riparian stands; some of them are focused on river fauna and include riparian vegetation as one of the attributes for the definition of a good habitat status (Rankin, 1989; Chovanec *et al.,* 2005)	

in larger ones. The active floodplain is the best indicator of the bankfull level. Therefore, the most feasible identifier of this level is the breakline of the floodplain (Rosgen, 1996). It is often helpful to use other field indicators to determine the bankfull level (such as the elevation associated with the highest le-

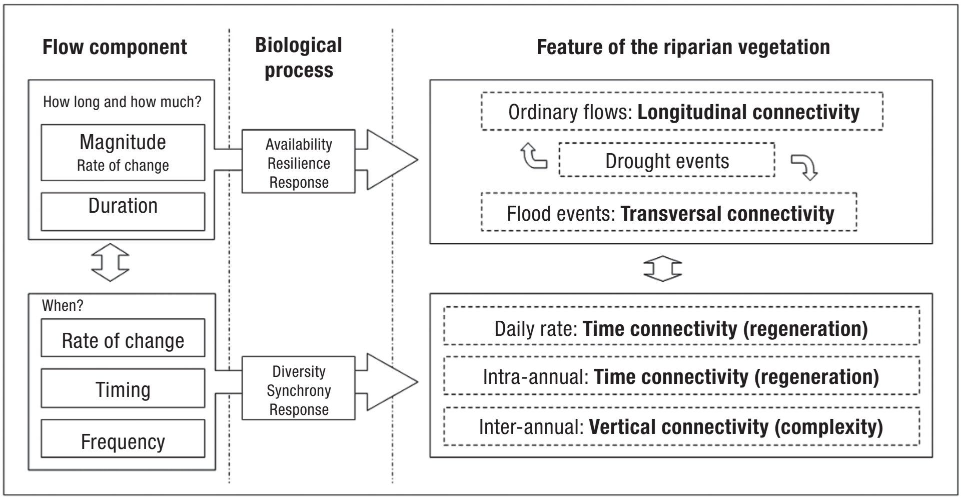

Figure 1. Rationale for the RFV index. The assessment features of the riparian vegetation were selected from those sustaining or associated to core biological processes. The hydromorphological pattern of the river was the basis for the design of an assessment index capable of guiding the riparian conservation and management. Flow components were thus related to biological processes to select the features finally incorporated to the RFV index.

vel of the deposition elements, changes in vegetation, changes in the slope that occur along transversal sections, changes in the bank materials, bank scouring or staining lines).

The use of the bankfull width as the fundamental variable for establishing the riparian sampling site was in accordance with some other tools, such as the Stream Visual Assessment Protocol-SVAP (Bjorkland *et al.*, 2001, 2006). The authors of SVAP used this geomorphic feature to define the area where the riparian quantity and quality was to be quantified. Thus, following the same assumption that is now considered in the RFV index: the prevalent influence of the hydromorphological pattern on the assessment procedure. These authors also consider forest connectivity to be an essential parameter to describe the status of the forest: their assessment tool evaluates if the forested riparian sites have a correct mix of shrubs, understory trees and new shrub and tree regeneration. Thus, their work also supports the design and application of the RFV index.

A longitudinal profile with a minimum length of twenty (20) bankfull widths (w_b) should be examined to determine the nature and presence of a representative indicator of the bankfull level for the reach. The indicated value (20 w_b) is in accordance with values recommended in the literature (*e.g.* Fausti *et al.*, 2004; Gerstein and Harris, 2005) and with the preliminary tests performed during the development of the RFV index.

RFV parameters

Longitudinal connectivity of the riparian forest

Longitudinal connectivity has long been recognised as a basic feature of river systems (Vannote *et al.*, 1980; Andersson *et al.*, 2000). For the RFV, this parameter is determined along a transect with a length of 10 to 14 times the bankfull width (to integrate the longitudinal connectivity along the different mesohabitats present in the channel; Keller and Melhorn, 1978) (Fig. 2). The selection of the specific length in the 10-14 width range is based on the heterogeneity of the channel ecomorphology found in the reach (the greatest heterogeneity will require a longer transect). This parameter

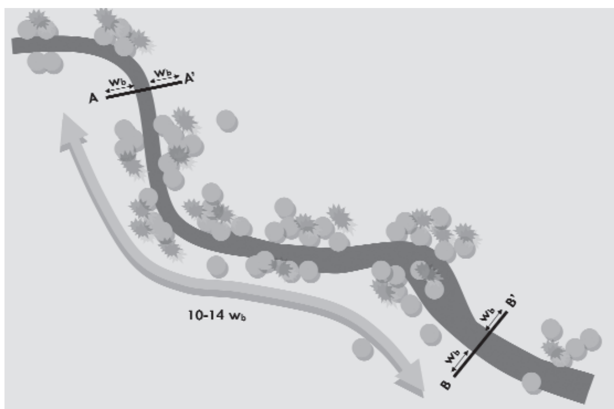

Figure 2. Selection of the study reach for application of the RFV index (wb = bankfull width).

evaluates the connectivity of the autochthonous riparian forest. The connectivity is assessed exclusively for all of the autochthonous tree and shrub taxa of the forest. Herbaceous taxa and allochthonous taxa are considered as discontinuities in the assessment. A lack of vegetation due to rocky obstructions in the channel, or in the confluence of the tributaries and secondary channels in the main channel, is not negatively interpreted when determining this parameter.

The longitudinal connectivity is analysed on both banks lines but not on in-channel islands. The assessment of this parameter is based on the procedure shown in Table 2, according to the percentage of the length of both banks that is covered with autochthonous riparian forest (> 90%, 70-90%, 50-70%, 30-50%, < 30%). The thresholds were set following the indications by Kinzig *et al.* (2006) and Knight and Cullen (2010) on vegetation connectivity.

Transversal connectivity of the riparian forest

In the last several decades, there has been a wide recognition of the importance of the lateral dynamics of

Table 2. Assessment of the longitudinal, transversal and vertical connectivity and the regeneration capacity of riparian forests for the RFV index

	Very good status	**Good status**	**Moderate status**	**Deficient status**	**Bad status**
Longitudinal connectivity, according to the percentage of the length of both banks covered with autochthonous riparian forest	More than 90%	Between 70 and 90%	Between 50 and 70%	Between 30 and 50%	Under 30%
Transversal connectivity, according to the percentage of channel sections that are covered with autochthonous riparian vegetation	More than 90%	Between 70 and 90%	Between 50 and 70%	Between 30 and 50%	Under 30%
Vertical connectivity (descriptive assessment)	Very dense autochthonous forests, with a shrub stratum composed of different species. Presence of nemoral, epiphitic and lianoid species	Dense autochthonous forests, with a shrub stratum composed of different species. Scarcity of nemoral, epiphitic and lianoid species. Specific presence of ruderal species and allochthonous species	Sparse forests of autochthonous and allochthonous species, with a scarce shrub stratum and a remarkable presence of ruderal species	Very sparse forests, abundance of allochthonous and ruderal species. Lack of riparian shrubs	Isolated trees or shrubs, mostly allochthonous. Dominated by ruderal species
Regeneration capacity (descriptive assessment)	Abundance of young individuals of riparian trees and shrubs, both under the forest cover and in open spaces in the channel (*e.g.* bars, islands)	Presence of young individuals of riparian trees and shrubs, both under the forest cover and in open spaces in the channel (*e.g.* bars, islands)	Specific presence of isolated young trees and shrubs, conditioned by non-natural channel dynamics or human activities	Absence of young trees and shrubs, conditioned by non-natural channel dynamics, or human activities	Only extra-mature and damaged trees and shrubs are present
Values	5	4	3	2	1

river systems for their adequate ecological functioning (Naiman and Décamps, 1997). The transversal connectivity of the autochthonous riparian forest is assessed along five to seven channel sections, equally distant and orthogonal to the channel axis, to assess the lateral dimension of the riparian vegetation in the channel transect. The connectivity is exclusively based on all the autochthonous tree and shrub taxa of the forest and the autochthonous macrophyte species. Other herbaceous taxa or allochthonous taxa are considered as discontinuities in the assessment.

The length of the channel sections should equal the total width of the riparian forest when this vegetation is connected to natural non-riparian vegetation or when the riparian forest grows in the maximum width allowed by the fluvial valley. If not the case, the section length should equal the bankfull width for any of the two banks (Fig. 2). This length includes the area most frequently covered by riparian vegetation in reference conditions (Bjorkland *et al.*, 2001; 2006).

The transversal discontinuities are considered to represent a lack of canopy cover, the existence of allochthonous taxa or the development of human land uses (*e.g.* any type of infrastructure, arable land, plantations and urban designs). The assessment of this parameter is based on the procedure presented in Table 2, according to the percentage of channel sections that is covered with autochthonous riparian vegetation (> 90%, 70-90%, 50-70%, 30-50%, < 30%). As in the former feature, the thresholds were set following the indications by Kinzig *et al.* (2006) and Knight and Cullen (2010) on vegetation connectivity.

Vertical connectivity (complexity) of the riparian forest

The vertical connectivity (*i.e.,* the complexity) of the riparian forest, as the third core spatial dimension of vegetation connectivity (Lindenmayer *et al.*, 2000), is assessed along the channel sections described for the previous parameter (ii) in terms of both the structure and composition of the vegetation (Fig. 2). This third parameter is assessed in the manner shown in Table 2, following a descriptive analysis that takes into account the forest density, the connectivity between strata and the relative presence of epiphytic, lianoid, nemoral and ruderal flora.

The assessment does not score negatively for a lower density of vegetation in forests where the vegetation is naturally sparse (*e.g.* riparian forests in temporary, intermittent or ephemeral channels) in reference conditions.

The final score of this parameter is an average of its partial values for both the riverbanks and in all of the studied sections. If the final score is not an integer, it is adjusted to the closest integer value. If the fractional part of the score is 0.5 or less, it is rounded down; otherwise, it is rounded up (*i.e.,* a final score of 3.7 would represent a good status [4], whereas a final score of 3.5 would indicate a moderate status [3]).

Regeneration capacity of the riparian forest

The determination of the short-, medium- and long-term dynamics of riparian forests is essential for recognising the future state of riparian stands (Amoros and Bornette, 2002). The regeneration capacity of a riparian forest is assessed along the transect that is defined for longitudinal connectivity. The assessment of connectivity is based on the existence of sprouts or saplings of autochthonous riparian trees and shrubs on both banks of the channel.

In cases where there is an almost a total lack of light, restrictive competition with other autochthonous plant species or rocky obstructions in the channel, the absence of regeneration of the riparian forest is not negatively factored into the RFV index. This fourth parameter is to be assessed in the manner shown in Table 2.

Final assessment of the ecological quality of the riparian forest

The final assessment of the ecological quality of the riparian forest is performed through a direct aggregation of the quantitative values obtained for each parameter. The final status of the riparian forest is classified using colour codes associated with Ecological Quality Ratios (EQRs), as defined by the Water Framework Directive. The qualitative assessments (Very Good, Good, Moderate, Poor and Bad) are defined according to the quality of the longitudinal, transversal and vertical connectivity and the regeneration capacity (Tables 3 and 4).

The final score for the riparian forest is determined from the score resulting from the aggregation of the partial parameters (Table 4). In some cases, when the

Table 3. Qualitative assessment, colour coding and the quantitative score range of the aggregate value of the RFV index

Status	Colour	Score
Very good – The riparian forest shows mostly continuous longitudinal and transversal connectivity; its regeneration is very well represented; and its structure and composition indicate a very high ecological value	Blue	19-20
Good – The riparian forest shows high longitudinal and transversal connectivity; regeneration is visible; and its structure and composition present a good ecological value	Green	16-18
Moderate – The riparian forest shows some alterations in the longitudinal and transversal connectivity; regeneration is scarce; or its structure and composition indicate human influence	Yellow	12-17
Poor – The riparian forest shows great alteration of the longitudinal and transversal connectivity; regeneration is almost non-existent; or the structure and composition of the forest show clear tracks of human influence	Orange	8-15
Bad – The riparian forest shows total alteration of the longitudinal and transversal connectivity; regeneration is non-existent; or the structure and composition of the forest show a total lack of ecological value	Red	4-11

Table 4. Quantitative assessment of the value of the RFV index according to the score obtained from its partial components and the correspondence with the colour code of the index. The table specifically identifies all of the potential combinations of the scores, independent of the order of the components

Sum of longitudinal, transversal and vertical connectivity and regeneration capacity	Colour code	Score of RFV components ordered from highest to lowest value
20-19	Blue	
18	Green	
17	Green	
	Yellow if	5552
16	Green if	5443 - 4444
	Yellow if	5533 - 5542 - 5551
15	Yellow if	5433 - 4443
	Orange if	5541 - 5532 - 5442
14	Yellow if	5333 - 4433 - 4442
	Orange if	5432 - 5522 - 5531 - 5441
13	Yellow if	5332 - 4333 - 4432
	Orange if	5422 - 4441 - 5521 - 5431
12	Yellow if	3333
	Orange if	5322 - 4422 - 4332 - 5421 - 5511 - 5331 - 4431
11	Orange if	4322 - 3332
	Red if	5411 - 4421 - 5321 - 4331 - 5222
10	Orange if	3322 - 4222
	Red if	4411 - 4321 - 3331 - 5311 - 5221
9	Orange if	3222
	Red if	4311 - 3321 - 5211 - 4221
8	Orange if	2222
	Red if	3311 - 3221 - 5111 - 4211
7-4	Red	

score can be associated with two possible conditions, the final identification is made by considering the partial scores of each parameter (as shown in Table 4). In this case, the four-figure code would not be dependent on the order in which the parameters were ordered; the four figures that compose the code in Table 4 are ordered from higher to lower value of the parameters. For example, if a forest was determined to have a score of 17 after aggregating the partial scores (*e.g.* longitudinal connectivity = 5, transversal connectivity = 5, vertical connectivity = 2 and regeneration capacity = 5), it could be classified as either a good or moderate status forest. However, because the score code is 5525, the status would be classified as moderate (yellow colour; Table 4).

Figure 3. Distribution of the six basins and the water bodies included in the analysis. They were chosen to evaluate the application of the RFV index on a wide array of hydromorphological and ecological conditions in riparian areas.

Practical application of the RFV index

Study area

The RFV index has been extensively applied in six large Spanish basins: the Guadiana and Guadalquivir basins in southern Spain, the Tagus and Douro basins in central Spain and the Cantábrico and Miño-Sil basins in northern Spain (Fig. 3 and Table 5). They characterise by highly variable environmental conditions, which induce the existence of very diverse riparian forests.

The climate in the Guadiana and Guadalquivir basins is Mediterranean-Continental, characterised by a well-defined dry season and remarkable thermal oscillations, which contribute to limited rainfall, high summer temperatures and very low summer flows (from June to September). The high variability of the flow regime enhances the high biodiversity in the riparian forests in these basins. In Guadiana, these forests are commonly dominated by willows (*Salix* spp.), narrow-leafed ash trees (*Fraxinus angustifolia* Vahl.), french tamarisks (*Tamarix gallica* L.) and tamujos (*Securinega tinctoria* L.); although in many channels, typical Mediterranean non-riparian species are mixed inside the riparian stands (*e.g.* holm oaks (*Quercus ilex* L.), cork oaks (*Quercus suber* L.), Portuguese oaks (*Quercus faginea* Lam.) and rockroses (*Cistus* spp.)). In Guadalquivir, the riparian forests are dominated by willows (*Salix* spp.), white poplars (*Populus alba* L.), narrow-leafed ash trees (*Fraxinus angustifolia* Vahl.), salt ce-

Table 5. Key variables that describe the set of water bodies included in this work

Basin	Catchment area (km^2)	Average rainfall (nm) (1940/41-2005/06)	Number of water bodies analysed
Guadiana	55,527	522	23
Guadalquivir	57,527	573	32
Tagus	55,772	648	32
Douro	78,859	612	40
Cantábrico	23,232	1,248 (western basin) 1,296 (eastern basin)	31
Miño-Sil	17,619	1,235	24
Total			182

dars (*Tamarix* spp.) and oleanders (*Nerium oleander* L.). The water bodies included in the study were distributed across their territories and characterised by highly diverse ecological and hydromorphological conditions (CHGuadiana, 2011; CHGuadalquivir, 2010).

The Tagus and Douro basins share a Mediterranean-Continental climate, which is strongly influenced by the altitudinal range and, in western regions, by the Atlantic. In these basins, riparian forests are dominated by alders [*Alnus glutinosa* (L.) Gaertn.], willows (*Salix* spp.), ash trees (*Fraxinus* spp.), poplars (*Populus* spp.), elm trees (*Ulmus minor* Mill.) and salt cedars (*Tamarix* spp.). The study included water bodies conditioned by a large hydromorphological gradient (CHTajo, 2007; CHDuero, 2010).

The Cantábrico and the Miño-Sil basins share an Atlantic humid climate (CHMiño-Sil, 2010; CHCantábrico, 2011). The thermal and rainfall oscillations in these basins are much more attenuated than in the other basins addressed in this study. This behaviour enhances the lower variability in the structure and composition of their riparian forests (Lara *et al.*, 2004), which are dominated by alders [*Alnus glutinosa* (L.) Gaertn.], large willows (*Salix* spp.) and mixed stands.

Methods

The analysis comprised the application of the RFV index in a wide range of physical and environmental conditions in different Spanish basins. Furthermore, the index was compared with the results derived from the application of another index traditionally used in Spain for the assessment of the status of riparian forests.

The first task was developed for 170 of the 182 preselected water bodies in the basins indicated in the study area, excluding those 12 with incomplete data (CHTajo, 2007; CHDuero, 2010; CHGuadalquivir, 2010; CHMiño-Sil, 2010; CHGuadiana, 2011; CHCantábrico, 2011). For all of these water bodies, the four parameters integrated in the index (longitudinal connectivity, transversal connectivity, vertical connectivity and regeneration capacity) and the final (aggregated) value were analysed.

In a second step, the value of the RFV index was compared to the status of the riparian forests as shown in the management plans of four of these basins (Cantábrico, Miño-Sil, Douro and Tagus). These four basins were selected due to the availability of data regarding the forest status in a wide range of water bodies. The forest status in all the plans was derived from the application of the QBR index (Munné *et al.*, 1998, 2003). The objective of this second step was twofold: i. to check the differences in the values derived from the application of both methods, and ii. to determine the feasibility of applying the RFV index under different hydromorphological and ecological gradients compared with previous approaches.

For both tasks (the application and then the comparison of the index), the statistical analysis was performed with SPSS 17 (IBM, 2008). For every water body the values of RFV and QBR range from 1 to 5, setting a gradient from 1 (bad status) to 5 (very good status). Due to these variables are qualitative-ordinal, correlation was verified by studying a contingency table, using the Pearson's Chi-squared test to investigate for significance correlation. The contingency table analyzed 5 × 5 pairs, implying 16 degrees of freedom in the Chi-squared test.

The Pearson´s Chi-squared test comparing RFV index and QBR index showed that there was not enough dispersion of data in the 5 × 5 contingency matrix. Due to lack of data in some cells of the RFV-QBR matrix, especially the cells which link high values of one index to low values of the other, the significance of the possible correlation could not be evaluated through this test. In order to characterize the behaviour of both indexes, a descriptive analysis was carried out. Two box-and-whisker plots were constructed using 170 case studies (Figs. 4 and 5). First plot shows the distribution of values in every basin, and the second plot compares RFV and QBR results for every basin.

Results

The RFV index was successfully applied in the 170 water bodies and allowed for the assessment of the riparian vegetation status in the four basins previously indicated. Fig. 4 shows the box-and-whisker plot, which illustrates the results extracted for any of those basins. The highest scores were calculated for the riparian forests of the northern Spanish basins (Cantábrico and Miño-Sil), which reached a median status of 4 (Good) despite having water bodies with degraded and poor forests. The status of the riparian stands in the Cantábrico basin was, in general terms, the best of the six basins analysed. The status of the forest found in the northern Spanish basins is consistent with the overall quality of the riparian areas in those regions,

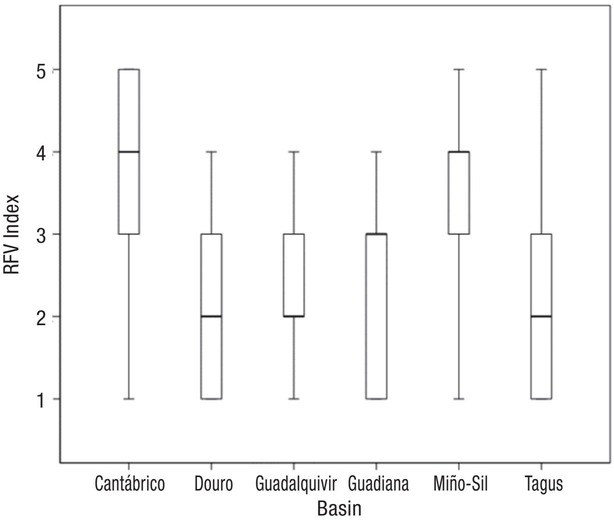

Figure 4. Box-and-whisker plots of the RFV values for the 170 study cases in the six basins included in the analysis. For every basin the box depicts three percentiles, 25%, 50% (median) and 75%, and the whiskers depict the minimum and maximum values. The plot illustrates the wide variability of conditions of riparian forests in the six basins. The best scores, despite this variability, were found in the basins of Northern Spain (Cantábrico and Miño-Sil).

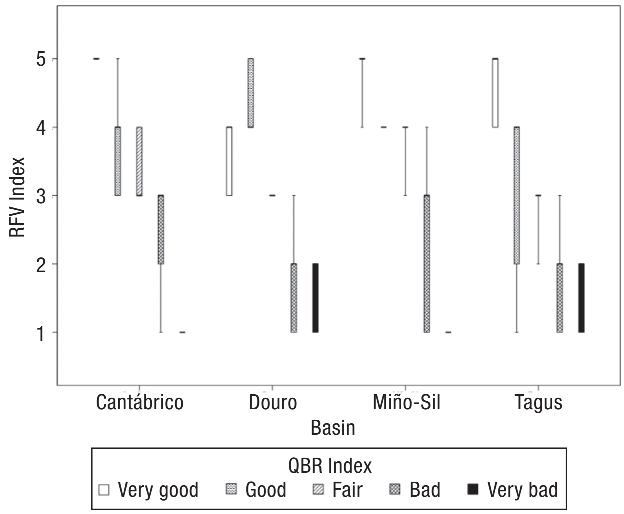

Figure 5. Box-and-whisker plots of RFV values compared with QBR values for the four basins used in the second step of the analysis. The box depicts three percentiles, 25%, 50% (median) and 75%, and the whiskers depict the minimum and maximum values. For every basin, the distribution of the QBR status for every RFV status is showed. The QBR is depicted by a pattern according to its different values from 1 to 5. *E.g.* good link could be found between both indexes in the Tagus and Douro basins: very bad QBR (black pattern) was matched to very low values of RFV.

which are not as affected by agricultural and urban uses as are the central and southern basins (Draft Management Plans: CHTajo, 2007; CHDuero, 2010; CHGuadalquivir, 2010; CHMiño-Sil, 2010; CHGuadiana, 2011; CHCantábrico, 2011).

The riparian stands in the Guadiana basin had a median status of 3 (Moderate), still showing a relatively high number of water bodies with forests that only reached a value of 2 (Deficient) or even 1 (Poor). The median status in the Guadalquivir, Douro and Tagus basins was even worse, just reaching the value 2 (Deficient). However, in those cases, there were also a number of forests with worse scores (1-Poor) and some that reached higher values (4-Good, or even 5-Very good in the Tagus basin). The range of the water bodies that were considered in the analysis comprised different physical and environmental conditions, which were detected by the index despite showing general trends in the overall assessment. These results are consistent with the general degree of alteration in those basins illustrated by the IMPRESS (Pressures-Impacts) analyses that are endorsed in the previously mentioned Draft Management Plans.

Regarding the comparison of RFV with the QBR index, Fig. 5 offers a schematic view of the corresponding values of the two indexes in the four basins for which QBR index data were available (Cantábrico, Miño-Sil, Douro and Tagus). The classes covered by the QBR index (Very good, Good, Fair, Bad and Very bad) are illustrated with different plots in the figure.

For the better-preserved basins (Cantábrico and Miño-Sil), both indexes supplied similar results for the better and worst-preserved riparian forests; Classes 1 and 5 of the RFV for both basins and Class 4 for the Miño-Sil basin showed similar conditions according to the QBR index. However, for lower-intermediate classes (2 and 3) of the RFV index, QBR supplied higher scores. That is, the RFV index penalised the existence of some degree of fragmentation in the spatial-temporal connectivity of the forest.

For the worst-preserved basins (Douro and Tagus), the trends were rather similar for both and somewhat different from the previous diagnosis. The riparian forests with the worst statuses (Classes 1, 2 and 3 of the RFV index) acquired very similar figures after the application of both indexes, only scoring slightly better for QBR. However, the stands with a better status showed a trend to be more positively scored with the RFV than the QBR index, although some cases may be found (for Class 4) where the RFV index again gave more negative scores.

Discussion and conclusions

The application of RFV to different case studies (170 water bodies) provided an assessment of the status of the conditions of riparian forests. The spatial connectivity and regeneration capacity of these forests, in the context of the associated river systems and the Draft Management Plans of the study basins, was described. The northern basins in Spain, which are less affected by human pressures along their floodplains and riparian areas, maintained higher quality in their riparian forests. In contrast, the worst-preserved basins, distributed along central and southern Spain (Douro, Tagus, Guadiana and Guadalquivir), received a lower score by the index.

In general terms, the comparison with the QBR method (Munné *et al.*, 1998, 2003) indicated that the RFV index assigns lower scores to riparian forests that show an intermediate degree of fragmentation, while extreme conditions are similarly described by both tools. The only exception to this trend is in some high-quality forests of big, largely altered basins, where the RFV index gives higher scores to the riparian stands. This exception could be related to the procedure used in both indexes for scoring the quality of the forest connectivity, or it could be related to the selection of the transects used for the assessment. Further applications of the RFV and QBR indexes in additional basins and forest types could help us understand the behaviour of the assessment tools in those specific situations. The findings of this paper are consistent with some early comparisons made by different operators (Lago, 2011; Simón, 2011; Sanz, 2012; Suárez, 2012) based on the comparative application of a large set of hydromorphological indexes for rivers in central Spain (including the RFV and QBR indexes). These preliminary works showed a very close functioning of both indexes under extreme conditions (very good or bad) and a tendency of the RFV index to assign lower scores to the riparian forests in intermediate conditions of alteration.

The RFV index showed and easy applicability, despite being based on a more thorough assessment of the riparian forests than previous tools. Other of its main advantages, its ability to describe the status of the forest regarding its ecological functioning, could also be successfully tested in a wide array of Iberian rivers. This better understanding of the forest structure is essential for the improvement of the riparian conservation and management. The RFV index would allow the adoption, in the whole set of rivers analysed, of management guidelines aimed at the protection of the better-conserved connectivity parameters, and the restoration of those in worse status. Being the index based on the geomorphic pattern of the river, the adoption of those measures is much easily related to the river structure. This fact would be especially important in Mediterranean rivers characterised by sustaining highly variable hydromorphological features.

Many previous works have already indicated an interest in developing flexible indicators for the assessment of riparian stands. Colwell and Hix (2008) found that, during the adaptation of the QBR index to rivers in Ohio (US), the assessment of riparian forests required an early adjustment to fit the specific physical and environmental conditions of channels in that region. These recommendations meet the procedure suggested by the RFV index, and the experience obtained from its application to a wide gradient of conditions. The inconveniences derived from the lack of representativeness of sampling sites during the assessment of riparian forests were also highlighted by Kleynhans *et al.* (2007) or Zogaris *et al.* (2009), who also proposed amendments to some previous tools used in Australia and Greece, demanding the adoption of methodologies based on the hydrological, geomorphological and ecological pattern of rivers. The RFV index also takes into consideration their findings, as shown through the application of the index to 170 case studies from six, very different, Spanish basins.

In short, the extensive application of the RFV and its comparison with previous assessment tools allow us to draw the following conclusions:

1. As shown for the diverse and complex situations found during the application of the index, the selection of the specific assessment area on the basis of the hydromorphological pattern of the associated channel allows for a better adaptation of the forest sampling to the river features.
2. The use of the spatial-temporal connectivity of autochthonous vegetation has shown to be a valuable indicator of the overall quality of riparian stands. The results derived from the application of the index to a large hydromorphological gradient support that assumption, which, through the comparison analysis, contrasted with other traditional procedures in different basins.
3. This work indicates that the procedure for determining the sampling transect and the quality of the ecological dynamics of the riparian forests is of little

relevance for stands that can be more easily assessed (given their extremely high or low quality or their homogeneity). However, the procedure is largely influential for more complex and partially altered situations.

4. The application of the RFV index to a wide range of different river types has demonstrated the index's consistency, ease of use and general applicability. However, further research could supply new evidence for the behaviour of the index in rivers characterised by singular hydromorphological patterns (*e.g.* in temporary channels).

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